STUDIES OF APS STORAGE RING VACUUM CHAMBER THERMAL MECHANICAL EFFECTS AND THEIR IMPACT ON BEAM STABILITY*

R. Lill, B. Yang, G. Decker, L. Erwin, J. Xu, J. Collins
Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439 USA

Abstract

As the Advanced Photon Source (APS) prepares for a large-scale upgrade, many of the fundamental limitations on beam stability have to be identified. We report on measurements of thermal mechanical effects of both the water, and air-handling systems impacting insertion device vacuum chambers (IDVCs). Mechanical stability of beam position monitor pickup electrodes mounted on these small-gap IDVCs places a fundamental limitation on long-term x-ray beam stability for insertion device beamlines. Experiments conducted on an insertion device vacuum chamber indicates that the beam position monitor blocks are moving with water temperature cycles at the level of 10 microns / degree C perpendicular to the beam direction. Measurements and potential engineering solutions will be described.

INTRODUCTION

The Advanced Photon Source (APS) is preparing for a large-scale upgrade and many of the fundamental limits on beam stability are being studied. One of the most critical locations for beam stability is at the insertion device (ID) points. The insertion device vacuum chambers (IDVC) are extruded aluminum with integrated beam position monitors (BPM) electrode housings machined out at each end of the IDVC. Three different versions of the vacuum chamber have vertical apertures of 12 mm, 8 mm, and 5 mm. The chambers are fabricated by extruding 6063 aluminum alloy to form a tube with the desired internal shape shown in figure 1. The exterior details, such as the BPM electrode housing, are machined to the finished dimensions. The IDVC have a pumping antechamber with non-evaporable getter strips. The wall thickness of the completed chamber at the beam orbit position is 1 mm. The design uses a rigid strongback that limits deflection of the chamber under vacuum despite the thin wall. Alignment of the vacuum chamber on its support is routinely accomplished with a precision of 75 microns over the entire surface, allowing minimum ID pole gaps.

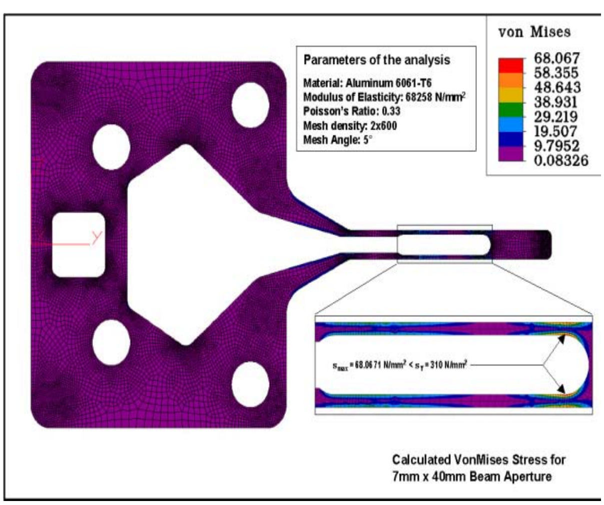

Figure 1: Storage ring IDVC cross section

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ID BPM MEASUREMENTS

The IDVC BPMs provide the critical steering data necessary to maintain beam stability through the ID. The BPMs are machined in precise platforms on each end of the IDVC. In figure 2 the BPM is shown on the far left of the picture. The BPM button electrodes mounted in the machined platforms have a 4 mm diameter. There are two button electrodes mounted on a single miniature vacuum flange. The horizontal separation of the buttons is 9.6 mm center-to-center, with vertical apertures of 12 mm, 8 mm, and 5 mm. The button signals are cabled out to the electronics racks located above the tunnel. Narrowband Bergoz switching-type receivers are connected to the IDVC buttons. Narrow-band (300 Hz) BPM electronics are used to reduce beam intensity dependence and long-term drift. The long-term (one week) drift associated with the BPMs at this time is 7 microns horizontally and 5 microns vertically peak-to-peak. Plans to improve this will also include upgrading the electronics in the future.

BPM Measurements

As the noise sources are eliminated and BPM improvements are made, new noise sources can be discovered. During the operations period October 2009, an elevated noise level was reported on several IDVC BPMs. The plot in figure 3 shows beam position and vacuum chamber water temperature as a function of time. It was determine at this time that the beam position measurement was correlated to the water cycle of the aluminium vacuum chamber. The period of the water cycle is about 15 minutes with a 2.8 microns/degree Fahrenheit (5.2 microns/degree Celsius) change in the vertical position.

Figure 2: Sector 32 ID vacuum chamber.

Water Cooling System for Aluminum ID Chambers

Many improvements have been made to the water temperature regulation system over the years from the original requirement of 78 +/- 1 degree Fahrenheit. Currently, the aluminium IDVC water system typically regulates the IDVC temperature at 78 +/- 0.05 degrees Fahrenheit peak to peak during normal operation. The cooling systems for the IDVCs are divided into twenty cooling skids with each skid containing two pumps [2]. One skid is responsible for supplying water to two of the forty sectors of the storage ring. This system has its own set of dedicated heat exchangers and a temperature controlling system. Chilled water is used to bring down the warm water temperature to 78° F ± 0.05° F. Flow rate is 50 gpm at a supply pressure of 50 psig.

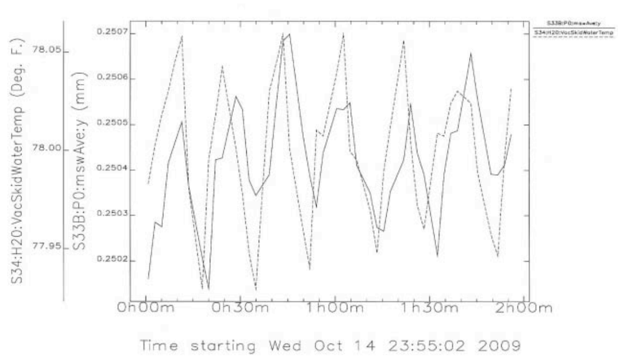

Figure 3: Sector 34 IDVC BPM readback and chamber water temperature variation over a two-hour period.

Chamber Measurements

During the December 2009 shut down period, the IDVC shown in figure 2 was instrumented to study the effects of the tunnel air and vacuum chamber water temperatures on mechanical stability. Two Keyence LK-G37 laser displacement sensors were used to measure the IDVC vertical positions as functions of air temperature and water cooling temperature. The Keyence sensors have a resolution limit of 0.05 microns. The BPM shown in figure 2 was instrumented with a laser sensor measuring vertical deflection and a second laser sensor was installed near the center of the five meter IDVC, also measuring vertical deflection. Five temperatures were recorded with the two vertical position measurements. Figure 4 shows recorded data during a period of three hours when the water temperature was deliberately changed in a controlled fashion over a range of 2.7˚ C. We can make the following observations from the data: (1) While the temperature of the vacuum chamber follows closely the temperature of the water flowing through it, the change in surrounding air temperature is only about one-tenth of the change in water temperature. Such a small change in air temperature did not affect the temperature of the stand within our measurement accuracy. (2) At the first temperature cycle, the vertical position of the BPM block appears to be a linear function of the water temperature: The higher the temperature, the lower the chamber height. It moves ~ 19 μm from peak to peak. (3) It is the vertical position of the center of the IDVC that exhibits a complex behavior: As we reduced water temperature from 23˚C, it moves up at a level of 10 microns/degree Celsius. However, when the water temperature reached 21.5˚C, the IDVC center reversed its motion and started moving down as the water temperature continues to decrease. This behaviour appears to be reproducible in the next two phases when the temperature is increased and decreased again. (4) Reexamination of the position of the BPM block shows that a small slope change existed in the temperature region where the IDVC reversed its direction of motion.

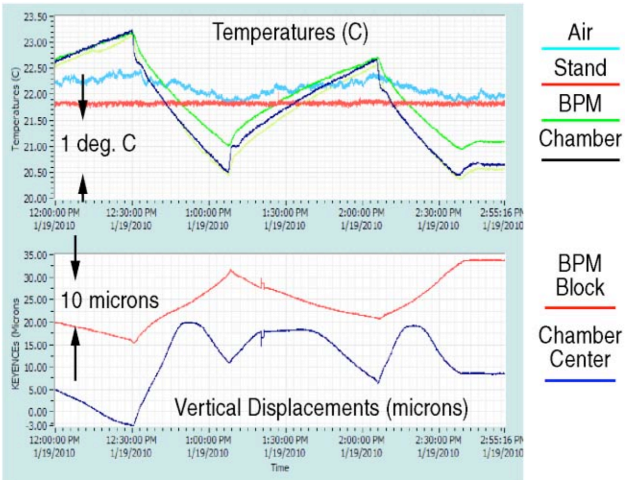

Figure 4: Variation of IDVC and BPM mechanical position with vacuum chamber water temperature.

We note that the IDVC strongbacks need not only provide stable support to the chamber, they also need to supply adequate torques in two planes to correct residual twisting and bending of the chamber and maintain its shape within specifications. During the temperature swing experiment, the floor, the strongbacks and the chamber, being made of different materials and at different temperatures, expanded differently, which changes the torques and the axial compression of the chamber. This results in a complex distribution of forces and torque in the over-constrained chamber. It is thus not surprising that the IDVC and BPM block expansion/contraction cycle is not a linear function of water temperature. Since the forces and torques applied to the chamber depends on the initial distortion of the ID chamber, they are not the same for different installations. This helps explain why the correlation of measured temperature dependence is stronger in some sectors but not in others. The horizontal movement of the BPM block was also measured but was less severe.

BEAM STABILITY

BPM Positioning

The experiments described in the last section clearly confirmed that the thermal distortion of the vacuum chamber leads to movements of the BPMs up to 10 µm/°C, or a 0.5 µm peak-peak for a temperature change of 0.05°C peak-peak. This is incompatible with the new stability requirements for the planned APS upgrade. To meet these requirements, we may request upgrades to the water temperature regulation and a new strongback design, but these changes are unlikely to be the whole solution. Our past experience shows that new sources of error will be discovered with increasing accuracy and precision of the BPM. We need to look at the issue differently: Now that the water system and strongbacks have been thoroughly worked on, and their thermal motion is well below the original stability tolerance, it is best that we measure these errors and compensate for them using the BPM electronics. We will measure the BPM position relative to the floor, and the beam position relative to the BPM, the sum of the two numbers gives the position of the beam relative to the floor, the reference system for the purpose of this paper. The contribution of the BPM movements to the beam position error is now reduced from the thermal movements to the measurement error of that movement. This approach will also address many other sources of error in addition to the two discussed here, such as beam heating transients from stored current changes, heating pattern changes due to fill pattern change, etc.

BPM Position Monitor Design

Figure 5 shows a conceptual design for a real-time BPM position monitoring system. The BPM is connected to a pair of Invar/Super-Invar rods, which are connected to swivels on the floor through precision distance meters. The distance meters are mounted on precision slides allowing free expansion along its length but rigid in all other degrees of freedom. The position of the BPM can be determined by elementary trigonometry using the parameters in the figure. Specifically, the change in horizontal (x) and vertical (y) coordinates can be given by measured changes of two distance meters:

$$\Delta x = \frac{\Delta L_1 \sin\theta_2 - \Delta L_2 \sin\theta_1}{\sin(\theta_1 + \theta_2)}, \qquad (1)$$

and

$$\Delta y = \frac{\Delta L_1 \cos\theta_2 + \Delta L_2 \cos\theta_1}{\sin(\theta_1 + \theta_2)}, \qquad (2)$$

where ΔL_1 and ΔL_2 are measured increments by the distance meters. This conceptual design has the following features: (1) The distance meters are located far away from the beam, reducing the possibility of radiation damage. (If needed, it is also easier to shield at the floor level.) (2) Mounting the distance meter at the floor level also makes it easier to design support and swivel since the sagging of rod is minimized. (3) Last but not least, it provides a reliable horizontal position measurement without resorting to an expensive support stand with strong horizontal stability.

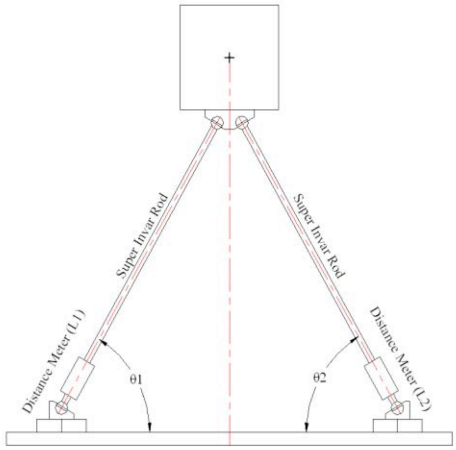

Figure 5: BPM position monitor concept.

Table 1 lists a number of candidates for the distance meter. Since this approach is applicable to rf BPMs and x-ray BPMs [3], each distance meter [4] will need to be evaluated and tested for each application before a final decision is made regarding its adoption. The radiation hardness of each of the following technologies will be evaluated before a final decision can be made.

Table 1: Characteristics of Distance Meters for a BPM Position Monitor

Technology	Resolution	Measurement Range	Cost
Potentiometer	200 nm	2 – 12 mm	Low
Optical Encoder	10 nm	5 - 500 mm	Medium
Capacitive Sensor	2 - 10 nm	0.1 – 0.5 mm	High-medium
Inductive Sensor	0.5 - 5 nm	0.5 – 5 mm	High
Optical Interferometer	10 nm	1 – 100 mm	High-medium

SUMMARY

We observed strong correlation of measured beam position signal with the ID chamber water temperature in several sectors during user beam operations. In beam-off, IN-SITU experiments, we observed a BPM position change at a rate up to 10 µm/°C. A nonlinear, complex behavior was observed in the chamber shape changed with water temperature changes. We propose to monitor the position of the BPM in real time during user beam operations to compensate for the distortion of the ID vacuum chamber. We presented a conceptual design to monitor the vertical as well as horizontal position change of the BPM and discussed a development plan based on this concept.

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[2] Private Communication

[3] B.X. Yang, G. Decker, S. H. Lee, and P. Den Hartog, "High-Power Hard X-ray Beam Position Monitor Development at the APS," these proceedings.

[4] Renishaw, http://www.renishaw.com, Lion Precision, http://www.lionprecision.com/, Micro-Epsilon, http://www.micro-epsilon.com/